DO-366 Appendix-C&D Update with Consideration for New A2 RDR Values

Prepared for

RTCA F2F

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Background and Objectives

- DO-366 Appendices C and D document analyses of the air-to-air radar (ATAR)'s field of regard (FOR) in terms of alerting times before a loss of DAA well clear (LoDWC)

- These analyses are to be repeated because
  - SC-228 Phase 2 work selects an alternative non-cooperative DWC
    - 2200 ft horizontal distance
    - 450 ft vertical distance

  - The one radar category in DO-366 will be expanded to 3 categories characterized by varying UA speed ranges
    - **High speed UA from 100 to 291 KTAS**
    - **Medium speed UA from 100 to 200 KTAS**
    - Low speed UA from 40 to 110 KTAS (not analyzed in this work)

ATAR Field of Regard (FOR) Requirements

- Radar Declaration Range (RDR) Requirement (computed by Adaptive Aerospace Group and NASA)
  - It is dependent on:
    - The bearing angle of the intruder aircraft to the ownship UAS
    - The size of the intruder aircraft which is based on the intruder aircraft speed
    - The speed of the ownship UAS (A1 for high speed, A2 for medium speed)
    - Assumed FOR angular ranges: $\pm$ 110° azimuth, $\pm$15° altitude
    - 1.5 deg/s turn rate for A1 UAS and 3 deg/s turn rate for A2 UAS
- Radar Closest Performance Range (RCPR) Definition
  - 4000 ft for A1, 2200 ft for A2
- Track declaration time
  - 15 seconds track delay when the intruder enters the FOR within the RDR

A1 (High Speed) UAS

Intruder Size	Nominal RDR [nm]
Small ($s_{int} \leq 100$ KTAS)	4.9
Medium ($100 < s_{int} \leq 130$ KTAS)	5.2
Large ($130 > s_{int}$ KTAS)	5.7

Intruder Bearing Angle	RDR Correction Factor		
	Small	Medium	Large
$\|angle\| < 30$	1	1	1
$30 \leq \|angle\| < 60$	0.59	0.67	0.76
$60 \leq \|angle\| < 90$	0.33	0.51	0.66
$90 \leq \|angle\| < 110$	0.17	0.25	0.40

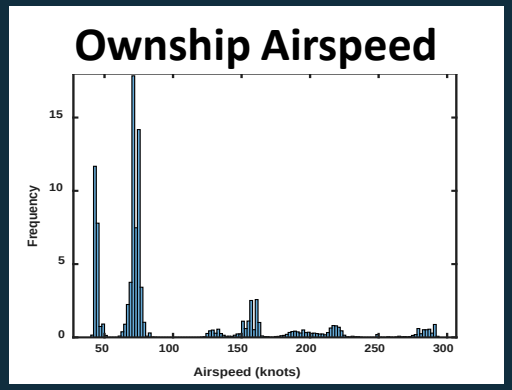
A2 (Medium Speed) UAS

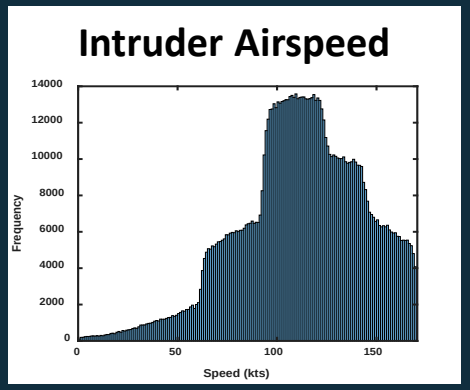
Intruder Size	Nominal RDR [nm]
Small ($s_{int} \leq 100$ KTAS)	3.6
Medium ($100 < s_{int} \leq 130$ KTAS)	3.9
Large ($130 > s_{int}$ KTAS)	4.4

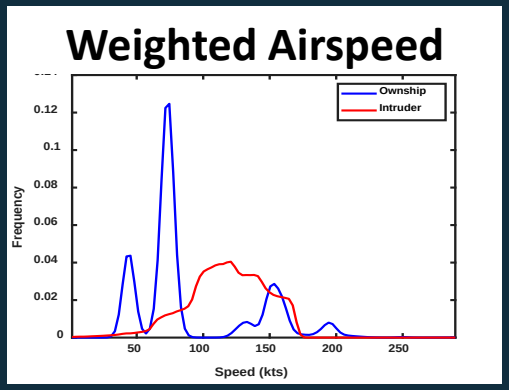
Intruder Bearing Angle	RDR Correction Factor		
	Small	Medium	Large
$\|angle\| < 30$	1	1	1
$30 \leq \|angle\| < 60$	0.69	0.78	0.84
$60 \leq \|angle\| < 90$	0.38	0.52	0.72
$90 \leq \|angle\| < 110$	0.23	0.29	0.42

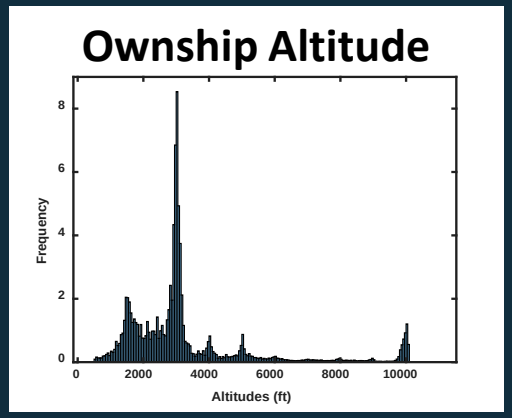
Full Encounter Set

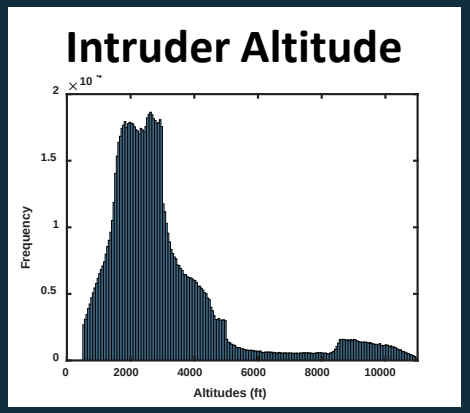
- 1 million encounters are created overlaying NASA UAS trajectories with VFR trajectories sampled from MIT Lincoln Lab's uncorrelated encounter model
- Weighted distributions represent the frequency at which the encounters actually occur
  - Trajectories with high ownship speeds occur infrequently in the original NASA UAS track data; trajectories with lower ownship speeds have longer track durations

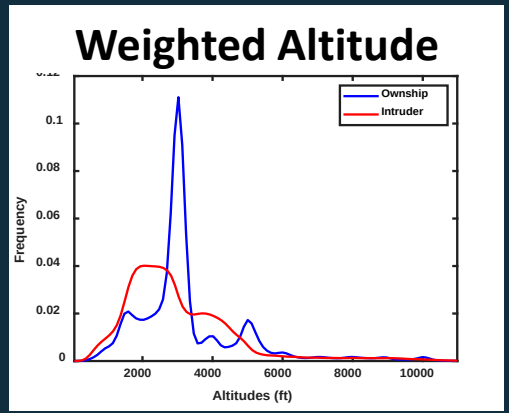












Encounter Set Stats

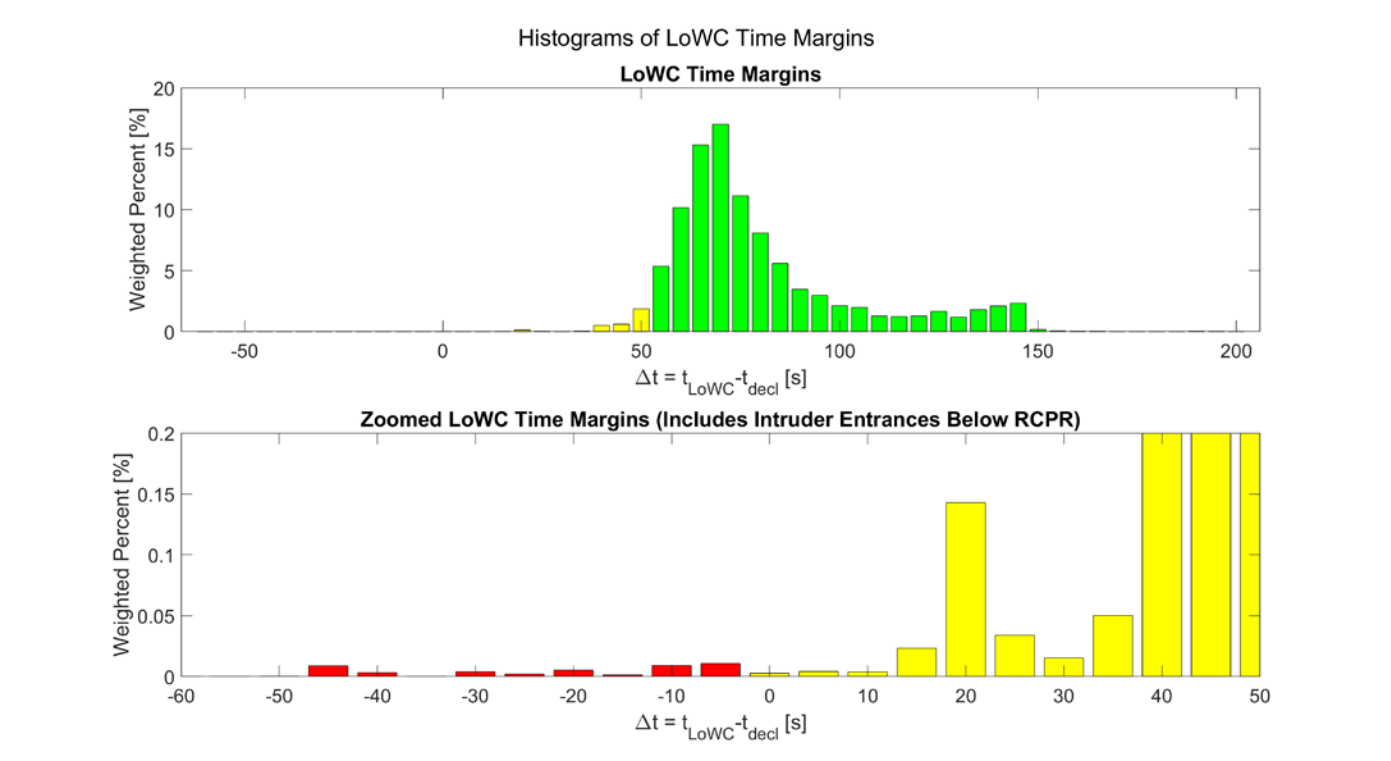
- The 1 million encounters were filtered to a set that includes only those encounters that are strictly within the speed bounds for A1 UAS
  - 100 KTAS to 291 KTAS
  - This includes all A2 UAS encounters as well
    - 100 KTAS to 200 KTAS
  - A1 UAS set includes 247,827 encounters
  - A2 UAS set includes 157,299 encounters

	A1 UAS (247,827 encs)			A2 UAS (157,299 encs)		
	# of Encs	% of Encs	Weighted % of Encs	# of Encs	% of Encs	Weighted % of Encs
LoWC	79,949	32.26	3.98	48,480	30.82	3.79
NMAC	12,252	4.94	0.20	7,849	4.99	0.19

Appendix D Definitions and Goals

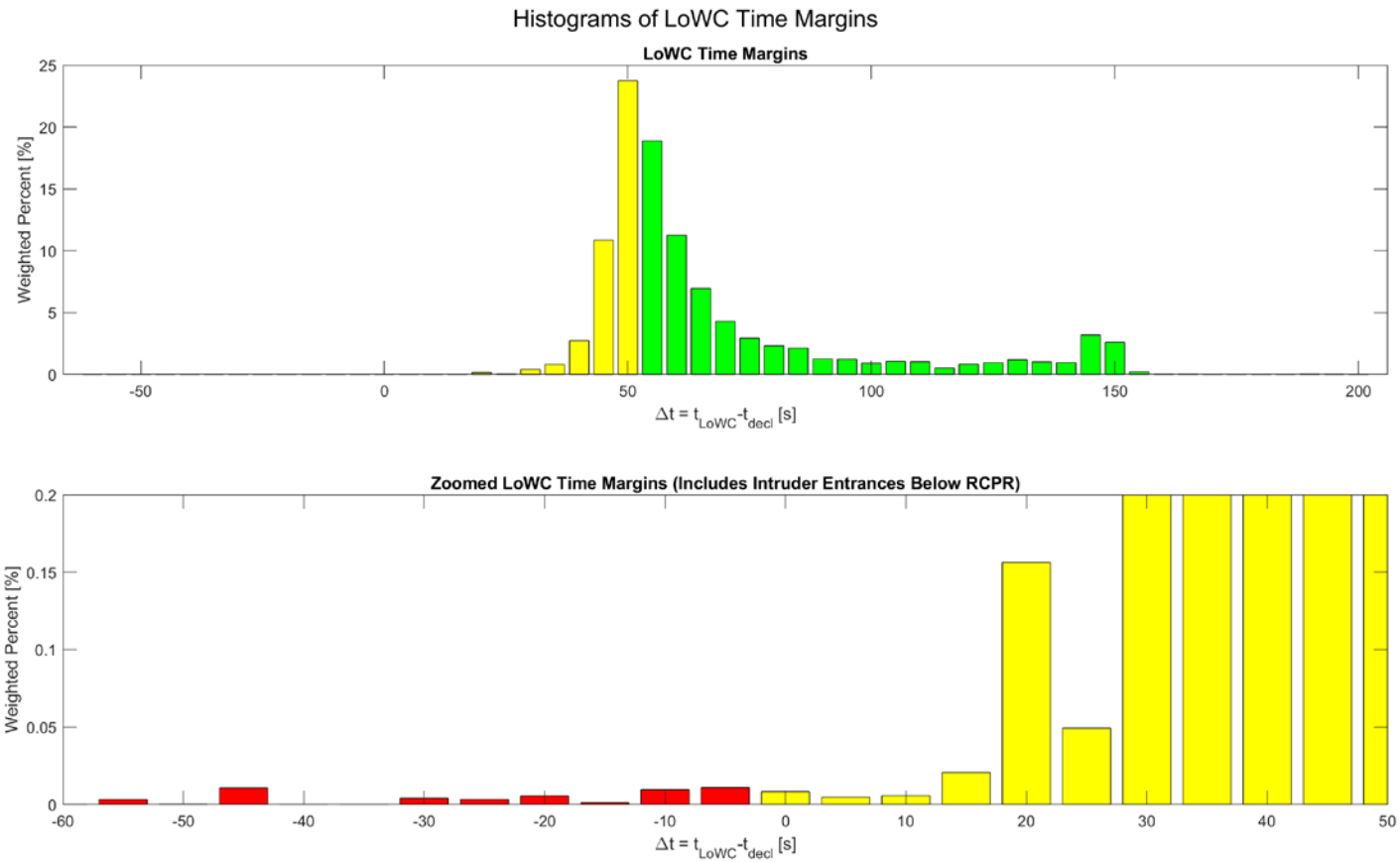
- App Goal: Compare RDR Time Margin to corrective alert requirements
- Definition: time margin $\Delta t = t_{LoWC} - t_{decl}$
  - t_{LoWC} = the time of first loss of well clear (LoWC)
  - t_{decl} = the time of track declaration
- Average corrective alert time: 55 seconds
- Late Alert time: 20 seconds

A1 LoWC Time Margin Data



- Green has a time margin of $\Delta t \geq 55\ s$
- Yellow has a time margin of $0\ s \leq \Delta t < 55\ s$
- Red has a time margin of $\Delta t < 0\ s$
- This includes ALL of the data. All of the Red and many of the smaller valued Yellow data are intruders that entered the FOR below the RCPR ($< 4000\ ft$).

A2 LoWC Time Margin Data



Appendix D Preliminary Results

Δt Bracket [s]	A1 UAS (79,949 total)		
	# of Encs	% of LoWC Encs	Weighted % of LoWC Encs
$\Delta t > 55$	69,555	86.99	95.16
$20 < \Delta t \leq 55$	10,352	12.95	4.61
$\Delta t \leq 20$	42	0.05	0.22

Δt Bracket [s]	A2 UAS (48,480 total)		
	# of Encs	% of LoWC Encs	Weighted % of LoWC Encs
$\Delta t > 55$	24,077	49.66	52.09
$20 < \Delta t \leq 55$	24,359	50.25	47.66
$\Delta t \leq 20$	44	0.09	0.23

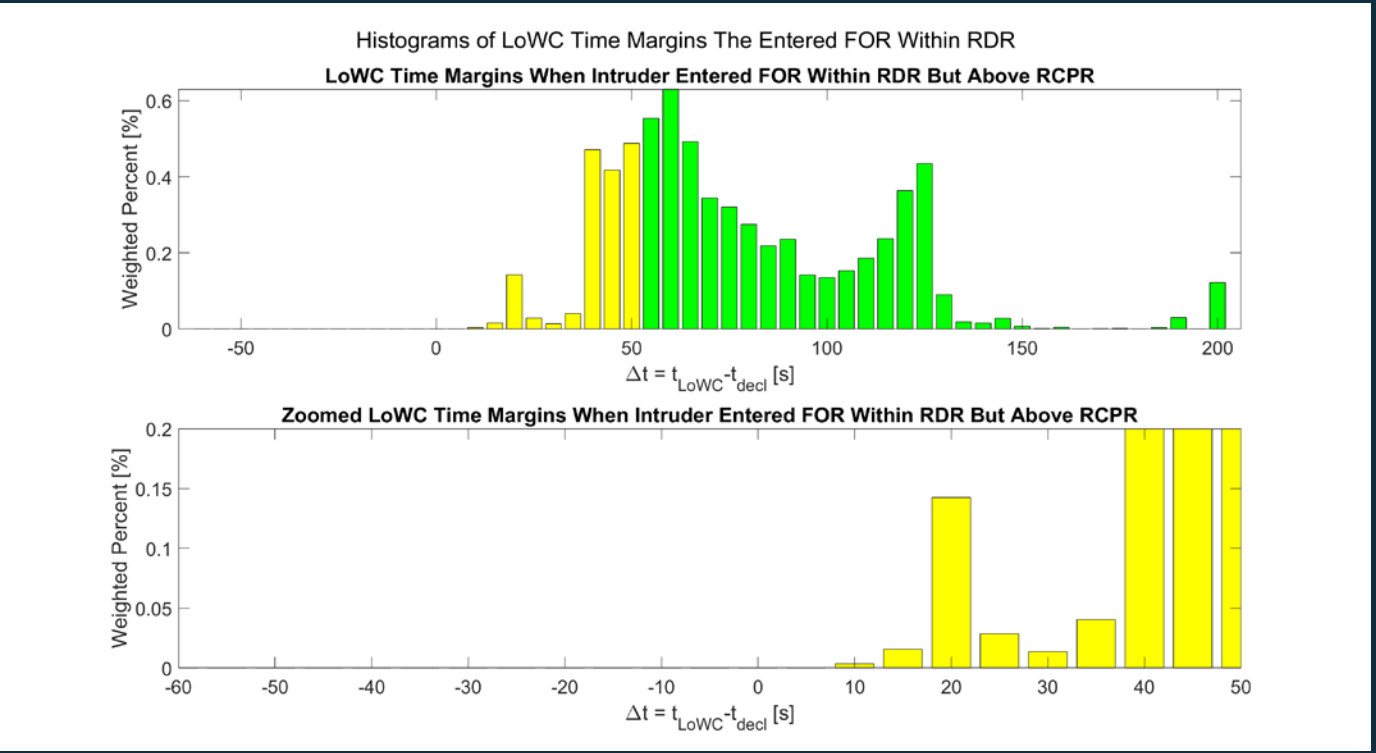
App D Preliminary Results Comments and Questions

- Late alert % is very low for A1 UAS. It appears that the RDR may be too conservative for A1
- Possible differences due to 1.5 deg/s turn vs 3 deg/s that is used for A2 UAS analysis
  - 3 deg/s results in RDR that is roughly 0.7-0.85 the RDR at 1.5 deg/s
- Rounding up in the way RDR definition:
  - Using worst case bearing across the bearing range (e.g. using 0 deg bearing for all of 0 to 30 deg)
  - Taking the largest RDR across ownship speed range
  - Using 1.5 deg/s turn rate

Appendix C Definition and Goals

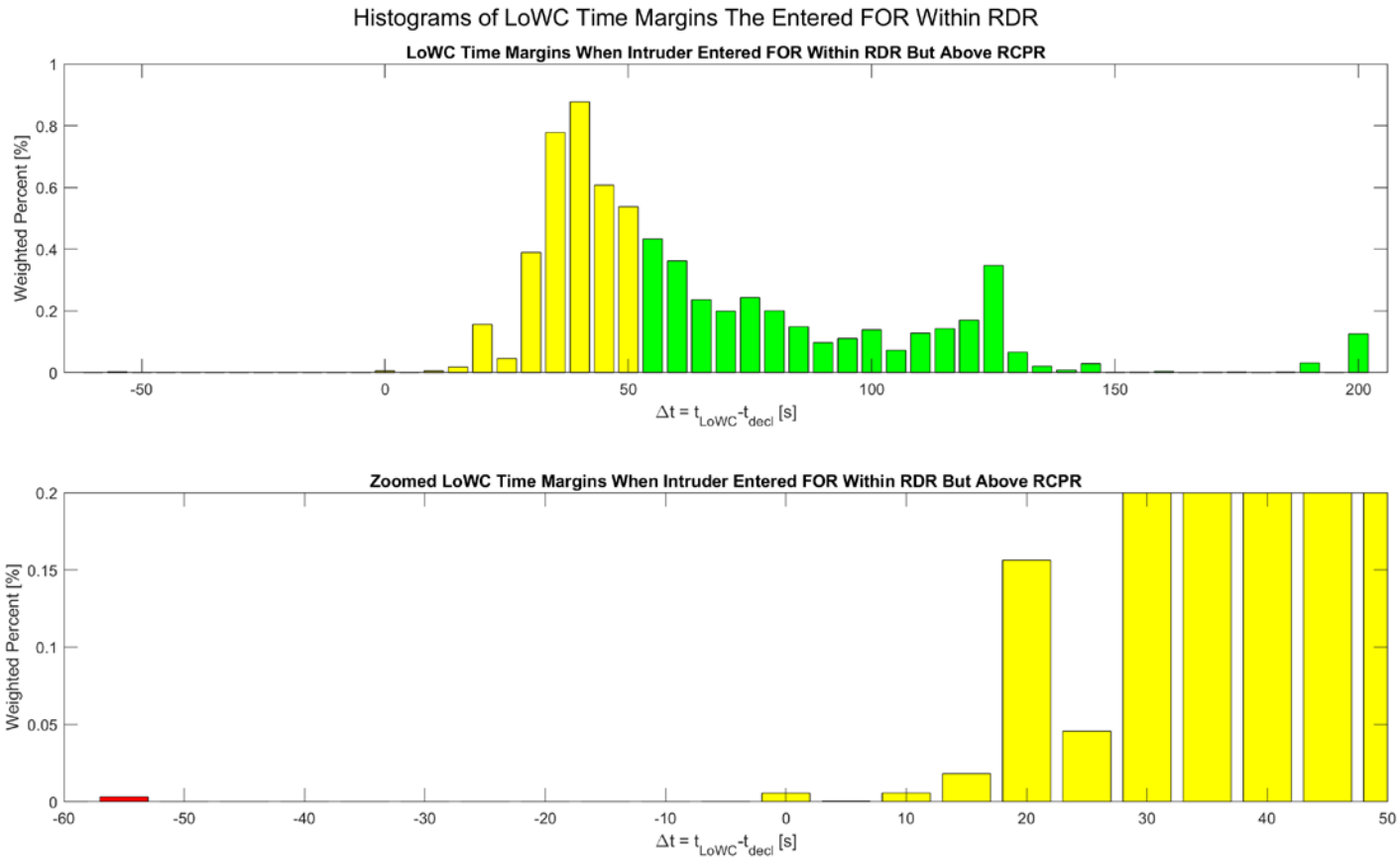
- App Goal: Determine effect of 15 second track delay when intruder enters FOR within RDR
- Definition: time margin $\Delta t = t_{LoWC} - t_{decl}$
- We want to find the percentage (and weighted percentage) of LoWC encounters entering the FOR below RDR that results in a $\Delta t \leq 30$ seconds
  - For a encounter first observed within RDR, a 15 second delay is considered for track declaration time.
- We also want to ignore any cases below the RCPR
  - RCPR defined as 4,000 ft horizontal distance for A1 and 2,200 ft for A2

A1 LoWC Time Margin Data When Intruder Entered FOR Within RDR

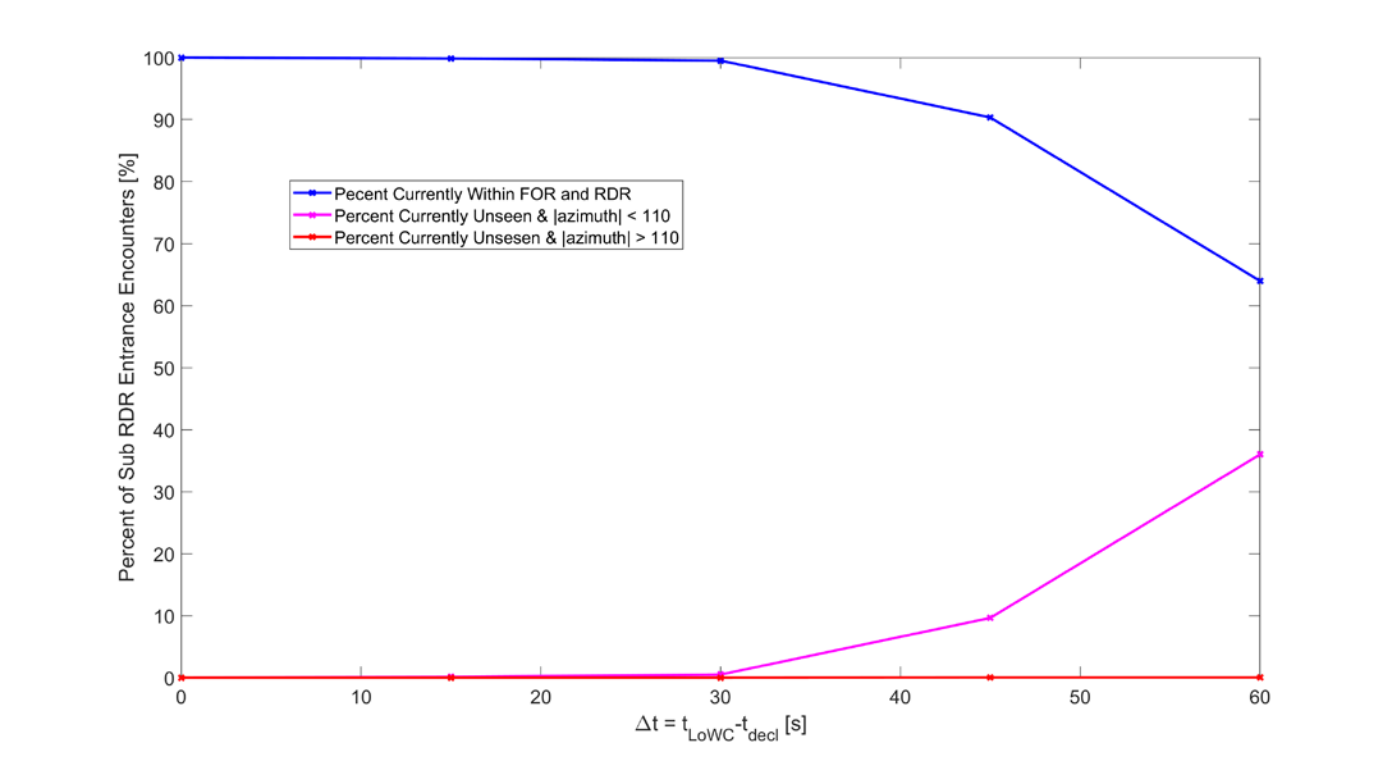


- Same color convention as before
- Removal of sub-RCPR FOR entrance data and only considering the cases where the intruder entered within the RDR.
- No more Red data.

A2 LoWC Time Margin Data When Intruder Entered FOR Within RDR

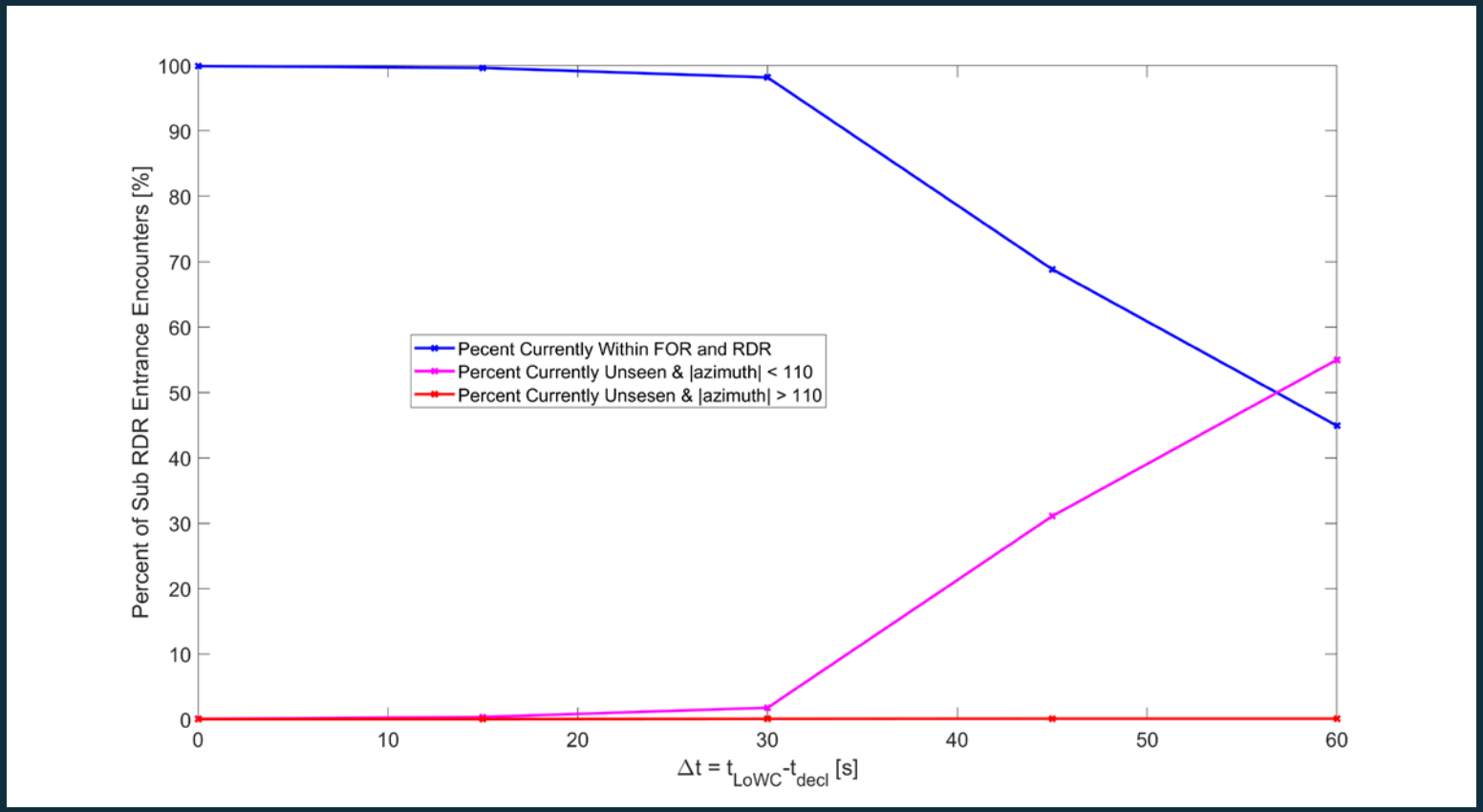


Percent of Sub-RDR Encounters Currently within the FOR relative to Δt for A1 UAS



- By $\Delta t = 30$ seconds, nearly all of the Sub-RDR entrance encounters are within the FOR

Percent of Sub-RDR Encounters Currently within the FOR relative to Δt for A2 UAS



- Even with the reduced RDR based off of the 3 deg/s turn rate, nearly all of the Sub-RDR entrance encounters are still within the FOR by $\Delta t = 30$ seconds

Appendix C Preliminary Results

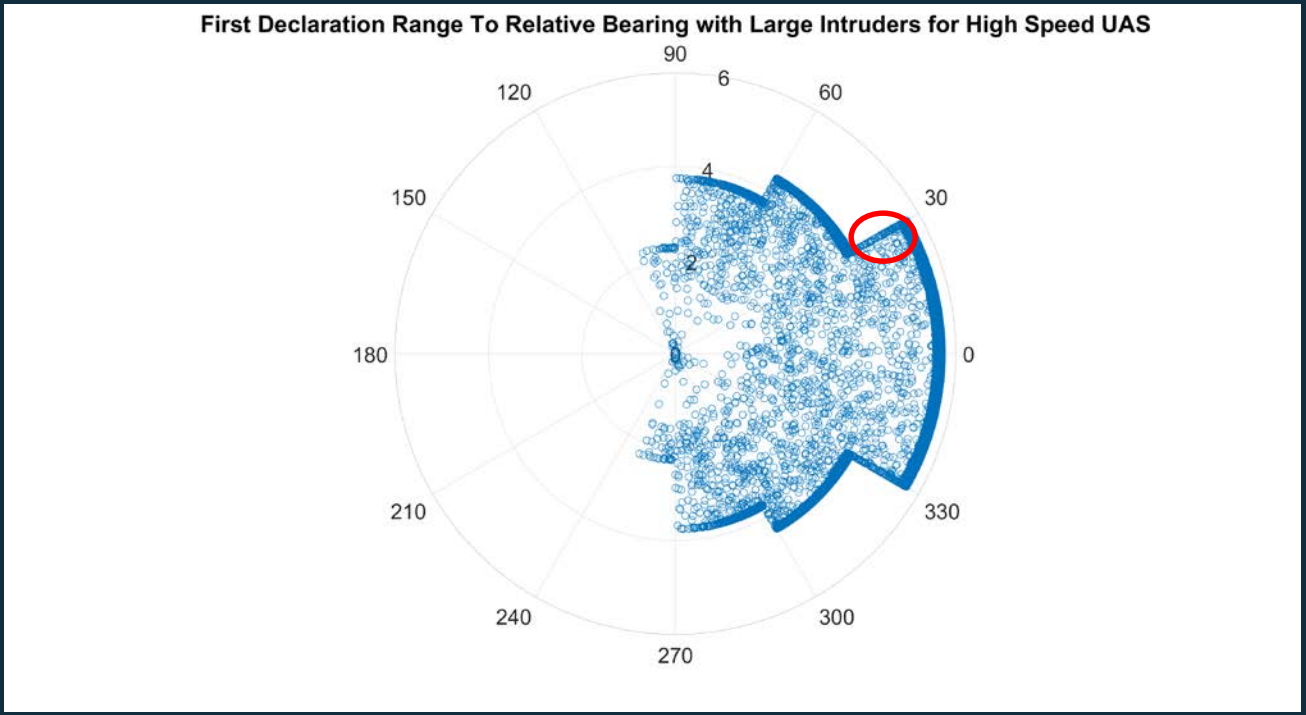
Where the intruder entered the FOR	A1 UAS (79,949 total)		
	# of Encs	% of LoWC Encs	Weighted % of LoWC Encs
Within RDR but above RCPR	3,642	4.55	6.57
Within RDR but above RCPR with $\Delta t \leq 30$ seconds (cases impacted by 15 second track delay)	18	0.02	0.20
Below RCPR	40	0.05	0.06

Where the intruder entered the FOR	A2 UAS (48,480 total)		
	# of Encs	% of LoWC Encs	Weighted % of LoWC Encs
Within RDR but above RCPR	2,832	5.84	6.63
Within RDR but above RCPR with $\Delta t \leq 30$ seconds (cases impacted by 15 second track delay)	52	0.11	0.29
Below RCPR	31	0.06	0.05

App C Preliminary Results Comments and Questions

- There are some significant changes in percent values from the previous work
- E.g. previously, 3527 encounters (3.3%, 2.1% weighted) of LoWC events could be affected by 15 sec delay where as current work suggests only 18 (0.02%, 0.2% weighted) for A1 and 52 (0.11%,0.29% weighted) for A2 encounters of the current set are impacted.
- This could be explained by differences in the set and our analysis parameters (no τ factor, >100 KTAS ownship, HMD is 2200 from 4000 last time).

Are the RDR Requirements and Definitions Suitable?



- Interesting cases to consider
  - Entrance in to the RDR through any of the radial faces (like what is circled in red)
  - What happens when the intruder enters the FOR at $1.01 \times RDR$ for a given bearing?
  - Is there a different definition or functional version of RDR that might make sense (i.e. something without the range discontinuities)?

Backup slides